

Instrument Packages for the Cold, Dark, High Radiation Environments. P.E. Clark¹, P.S. Millar², P.S. Yeh², B. Beaman², D. Brigham², S. Feng². ¹Catholic University of America@NASA/GSFC, Greenbelt, MD 20711; ²Goddard Space Flight Center, Greenbelt, MD 20771 (Correspondence email: Pamela.E.Clark@NASA.gov).

Introduction: We are developing a small cold temperature instrument package concept that integrates a cold temperature power system and radhard ultra low temperature ultra low power electronics components and power supplies now under development into a ‘cold temperature surface operational’ version of a planetary surface instrument package. We are already in the process of developing a lower power lower temperature version for an instrument of mutual interest to SMD and ESMD to support the search for volatiles (the mass spectrometer VAPoR, Volatile Analysis by Pyrolysis of Regolith) both as a stand alone instrument and as part of an environmental monitoring package.

Phase 1 [1]: Previously, we launched a multi-year effort to develop strategies and design concepts for ALSEP-like stand-alone lunar surface instrument packages with minimized mass/power requirements and without dependence on radioisotope-based batteries [1,2]. An initial attempt to design a conventional environmental monitoring package with a solar/battery based power system led to a package with unacceptably large mass (500 kg) of which over half was battery mass. Our Phase 1 work led to considerable reduction (5x to 100 kg) in the initial mass of such a concept deployable near the poles (up to a few days of darkness once a year) by incorporating a) radiation hard, cold temperature electronics readily available but not routinely considered for deep space missions and b) innovative thermal balance strategies through use of multi-layer thin materials and gravity-assisted heat pipes.

Phase 2 [2,3]: We investigated strategies and leveraged ongoing work in the universal incorporation of Ultra Low Temperature/Ultra Low Power (ULT/ULP) digital and analog electronics, lower voltage power supplies, and distributed or non-conventionally packaged power systems. ULT/ULP radiation hard digital components, developed at GSFC and through partnerships with the U. Idaho and the DOD National Reconnaissance Office, have successfully been demonstrated to offer orders of magnitude savings in power consumption and thermal tolerance. CULPRiT (CMOS Ultralow Power Radiation Tolerant) technology has successfully flown on NASA’s ST5 90 day mission. Similar high end channel coder and compression chips have been requested for use in MMS, and GOES-R missions. We are currently leveraging DARPA funding to our partner at U. Idaho’s CAMBR for the development of ULT/ULP electronics, as well as RHBD (Radiation Hardened by Design) technology which provides protection for the electronics against radiation damage

[3]. The 0.35μ CMOS RHBD ULP electronics was demonstrated in NASA’s ST-5 mission for a chip operating at 0.5 volt logic in space and achieved 100:1 power reduction as compared to its 5 volt part in space. Cryotesting has indicated that our small Si RHBD CMOS chips can deliver >80% of room temperature performance at 40K (nominal minimum lunar surface temperature). The ultimate goal is the development of ULT/ULP analog and digital logic chips for use in system on a chip which includes CPU as well as other components.

Phase 3 [4,5] Our work will support development of small batteries and power supplies operating efficiently over many diurnal cycles at lower voltages and colder temperatures (down to a minimum of -50°C , with a goal of -80°C). Building on ST-5 technology, our distributed micro-battery-based power supply concept incorporates cold temperature power supplies operating with a 4V or 8V battery. Improvements in operation of Li-based battery systems (West *et al*, 2000) below -40°C have already been demonstrated in rechargeable Li-ion systems (with low temperature organic electrolyte systems to enhance conductivity and charge transfer (Lithion, SAFT)), as well as lower TRL Li-S and Li-CuCl₂ systems (Kolawa *et al.*, 2007). To support the proposed instruments we are testing some low temperature battery systems for capability (capacity, power density, and recharge) and efficiency of operation below -40°C using available Li-Ion systems at appropriate rates of charge/discharge. Advances in MOSFET technology provide the lower voltage thresholds for power switching circuits incorporated into our low voltage power supply concept. Conventional power conversion has lower efficiency. Our low power conversion circuit concept based on ‘synchronous rectification’ will produce stable, regulated voltages as low as 0.6V with at least 85% efficiency. Requirements for consumer electronics have produced a variety of low power circuits designed to operate from one or two Li-ion batteries in series. These parts are generally rated for operation down to -40°C with a few rated for -55°C . These and other representative circuits must be tested for reliable operation at temperatures extending into cryogenic regions. If the entire electronic circuit including power supply will operate reliably at cryogenic temperatures, then only the battery itself will need to be heated to its minimum operating temperature, saving a significant amount of battery power. It is also possible to harness thermal discharge of the circuits as a heat source for the batteries. We will explore the potential for the use of cold temperature batteries to

provide the power system for our optimized mass spectrometer instrument package.

Improvements in operation of Li-based battery systems below -40°C have already been demonstrated in rechargeable Li-ion systems (Yardney-Lithion, SAFT low temperature organic electrolyte systems to enhance conductivity and charge transfer, and lower TRL Li-S and Li-CuCl₂ systems)..

Our collaborators at JPL [5] have successfully operated Li-based batteries with special electrolytes down to -60°C , with the goal of achieving -80°C in the short term. We have obtained representative batteries and voltage regulators. Several of the available highly efficient voltage regulators that use switching technology or synchronous rectification have already been tested successfully to -50°C , confirming minimum performance specifications. Currently, we have initiated cold temperature testing of power system components for and designing one or more rechargeable battery systems capable of operating with stability below -40°C over repeated cycles with minimal mass and power. We are performing an instrument integration study of an advanced version of an instrument/instrument package concept that fully incorporates low temperature low power technologies. If the entire electronic circuit including power supply will operate reliably at cryogenic temperatures, then only the battery itself would need to be heated to its minimum operating temperature, saving a significant amount of battery power.

Applications: A newer generation CMOS RHBD technology was developed for 0.25μ for several ASICs for NASA's missions including LDCM, GOES-R, MMS (Magnetospheric Multi-Scale Mission). This is operating at a core voltage of 2.5 volt. The circuit has already passed low-temperature test down to 25K, operating at 80% efficiency at 40K. At this level of CMOS technology, one ASIC can include over several million transistors to support complicated processing logic. A 130nm RHBD test chip with memory elements is being developed. At this CMOS node, core voltage will drop to 1.2 volt or 1.1 volt and will allow system-on-a-chip concept to be implemented. A 90nm RHBD test chip has been submitted for fabrication. At this CMOS node, core voltage will be close to 1 volt and will allow us to realize sub-system as well as system power reduction at relatively large scale, estimated for over 50% for conventional C&DH system. So far, the developed digital core includes several communication channel coders, several high-end data compression coders, reconfigurable base-band modulator, enhanced micro-processor CPU, mass-memory protection circuit, large-scale multi-cross-correlators-on-a-chip and on-chip memory modules. These will be available for any System on a Chip concept in addition to other openly

available cores such as the Spacewire, ARM processor, etc.

By integrating ULT/ULP electronics and power components fully in VAPoR, we believe we could provide a demonstration ISRU instrument for surface composition, including volatiles and other species up to mass 64 with detection limits of <1000 ppm for under 5 kg mass within an instrument package of well under 60 kg,. This estimate would not include the sample acquisition device for samples. We would collaborate with those developing laser ablation components capable of vaporizing samples at the surface and as a function of depth on the order of centimeters.

References: [1] Clark, Millar, Yeh, Lorenz, Feng, Powell, Beaman, Brown, and Leshin, 2009, 'Enabling Technology for Lunar Surface Science", in proceedings of *Space, Propulsion & Energy Sciences International Forum (SPESIF-09)*, edited by Glen A. Robertson, AIP Conference Proceedings, Melville, New York (2009); [2] Clark, Millar, Beaman, Yeh, Cooper, Feng, Young, 2010, 'Ultra Low Temperature Ultra Low Power Instrument Packages for Planetary Surfaces,' in proceedings of *Space, Propulsion & Energy Sciences International Forum (SPESIF-10)*, edited by Glen A. Robertson, AIP Conference Proceedings, Melville, New York, (2010). [3] Maki and Yeh, 'Radiation Tolerant Ultra Low Power CMOS Microelectronics Technology Development Status, ESTO Conference (online) (2003); [4] Clark, Millar, Yeh, Feng Brigham, Beaman, 'Small Cold Temperature Instrument Packages', in proceedings of *Space, Propulsion & Energy Sciences International Forum (SPESIF-11)*, edited by Glen A. Robertson, AIP Conference Proceedings, Melville, New York (2003); [5] Smart and Bugga, 'Improved Low Temperature Performance of Li-Ion Cells Using New Electrolytes, NASA Tech Briefs, Materials, NPO-46180 (2010).